LA-UR-18-30610
Approved for public release; distribution is unlimited.

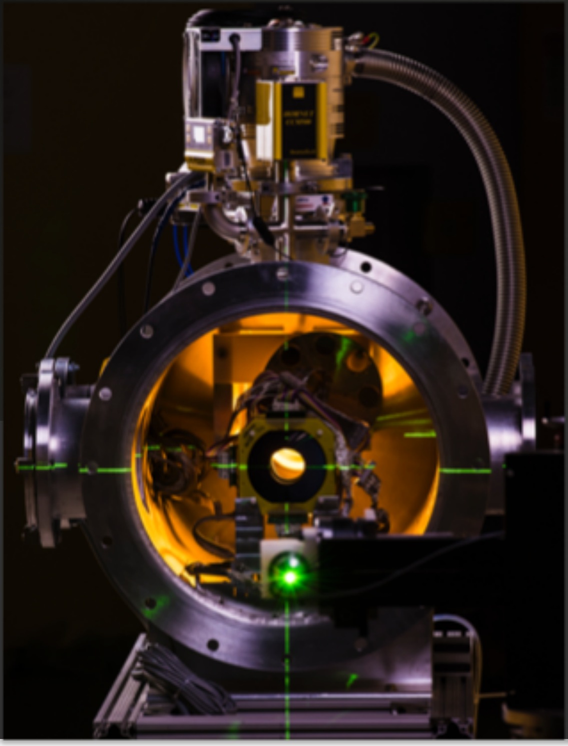
Title: Updates on neutron-induced reaction studies at LANSCE

Author(s): Lee, Hye Young; Kuvin, Sean Andrew; Zavorka, Lukas; Georgiadou, Anastasia; Hale, Gerald M.; Kawano, Toshihiko; Paris, Mark W.; Vermeulen, Christiaan; Bennett, Kevin; Nortier, Francois Meiring; Birnbaum, Eva R.; Brugh, Mark; Kim, Hyeong Il; Perdikakis, Georgios; Tsintari, Pelagia; Frohlich, Carla; Grinder, Mara

Intended for: US Nuclear Data Program Week, 2018-11-05/2018-11-09 (Brookhaven, New York, United States)

Issued: 2018-11-05

LAUR-18-xxxxx



Updates on neutron-induced reaction studies at LANSCE

Physics Division: H.Y. Lee, S. Kuvin, L. Zavorka, A. Georgiadou

Theory Division: G. Hale, T. Kawano, M. Paris

Chemistry Division: C. Vermeulen, K. Bennett, M. Nortier, E. Birnbaum, M. Brugh

Korea Atomic Energy Research Institute: H.I. Kim

Central Michigan U.: G. Perdikakis, P. Tsintari

North Carolina S. U.: C. Frohlich

Michigan State U.: M. Grinder

*** students, postdocs, guest scientists**

Los Alamos NATIONAL LABORATORY EST.1943

NNSA National Nuclear Security Administration

Progress updates on LENZ, ALSOLENZ, and miniLENZ

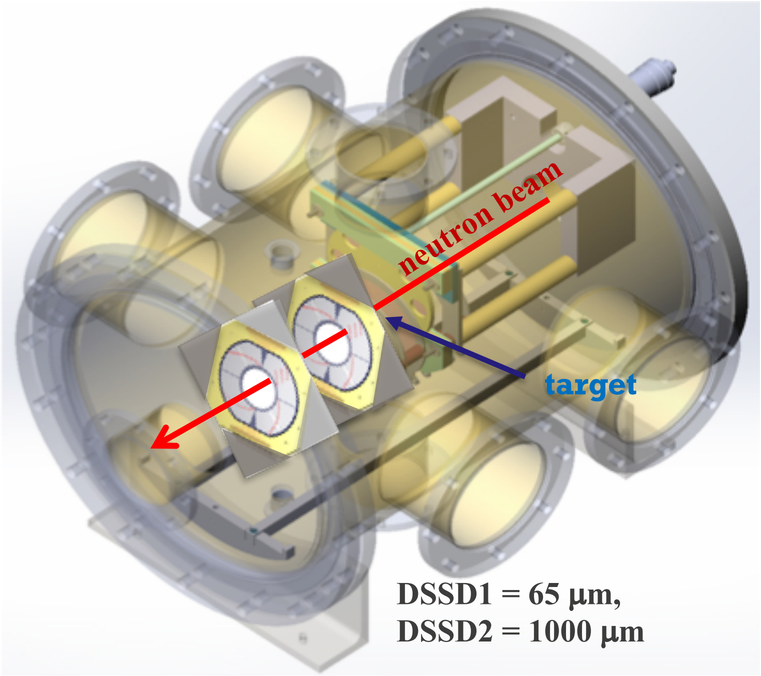
- High-precision $^{16}O(n,\alpha)^{13}C$ cross section study
- Newly evaluated angular distributions on (n,z) reaction cross sections
- Validation of new evaluated data using MCNP6 and GEANT4
- Gas-production cross section studies for radiation damage on structural materials like Cr, Mn, Fe, Co, Ni, etc.
- (n,z) reaction study on radioactive samples

LENZ $^{16}O(n,\alpha)$ data runs and setups

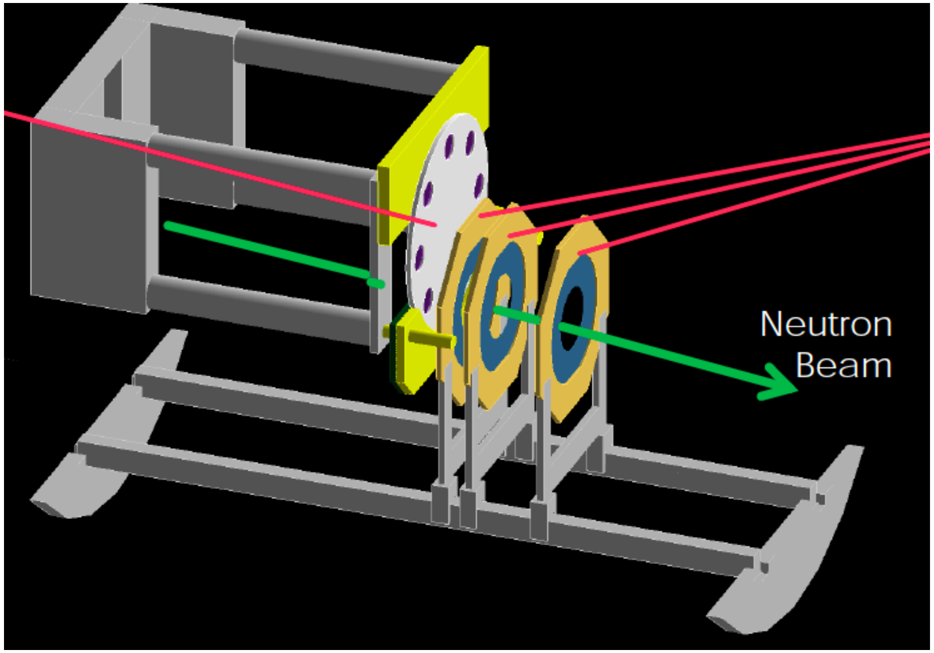
TABLE I: LANSCE Data Sets

Run Cycle Year	Target	Detector thickness (μm)	Distances from target (cm)	Solid Angle	Run Time
2016	Ta_2O_5	71 & 1000	3.9 & 7.0	$19° - 51°$	14 days
2016	Ta blank	71 & 1000	3.9 & 7.0	$19° - 51°$	4 days
2017	Ta_2O_5	65, 300 & 500	2.0, 4.1 & 9.1	$15° - 67°$	24 days
2017	Ta blank	65, 300 & 500	2.0, 4.1 & 9.1	$15° - 67°$	5 days

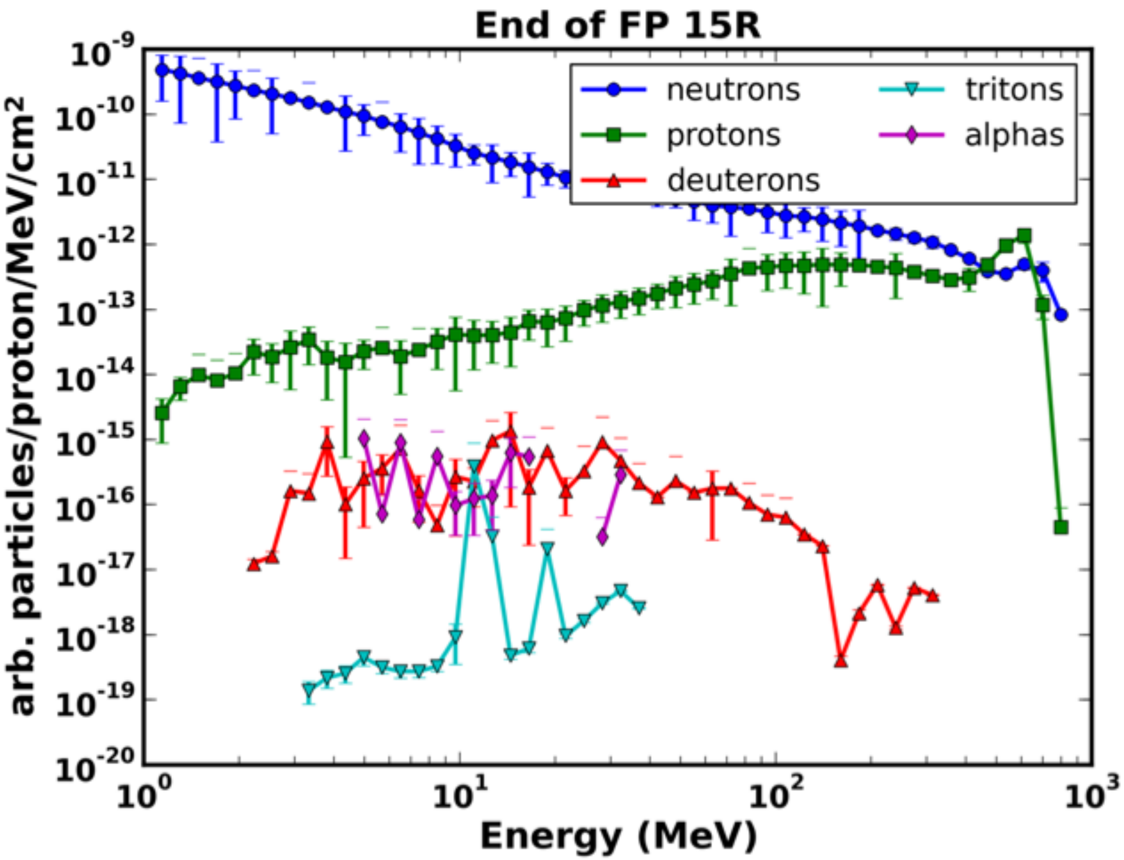
2016 Setup

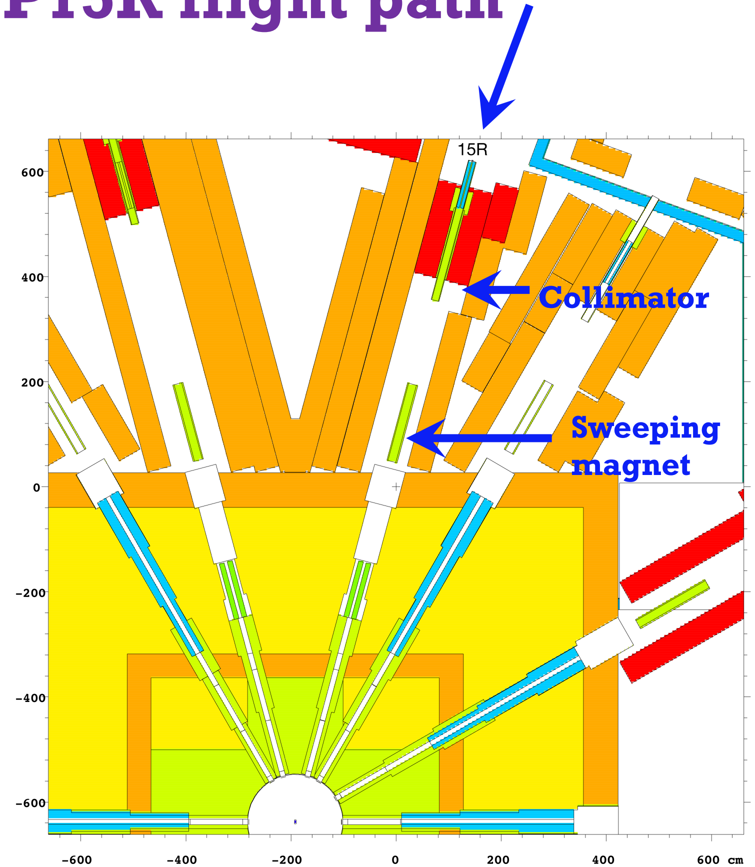


2017 Setup



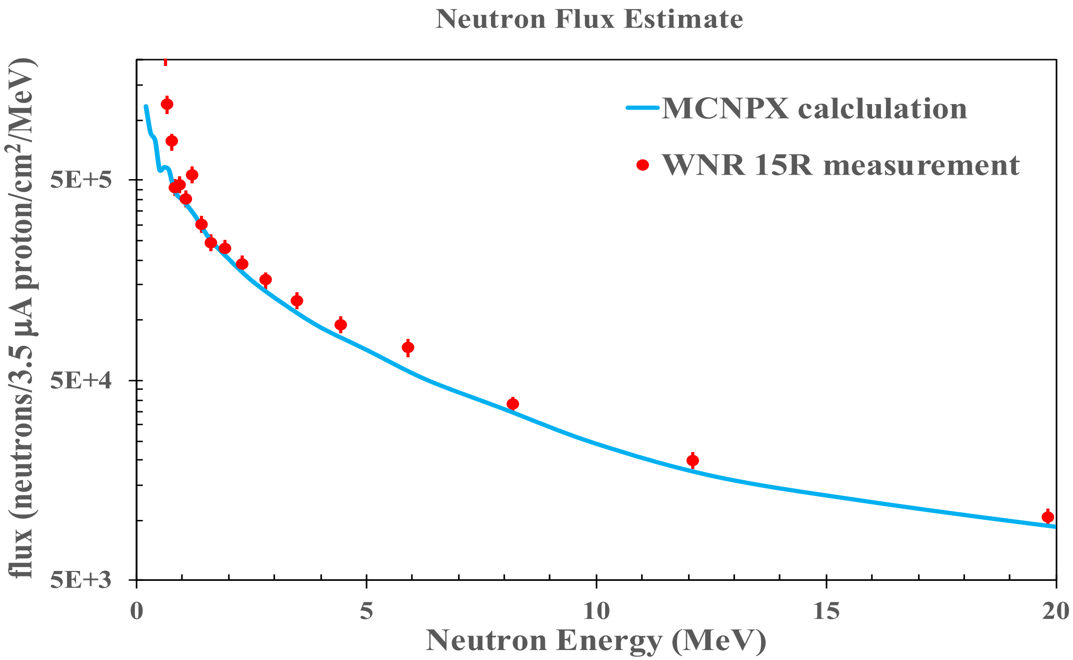
MCNPX modeling of WNR FP15R flight path





- Charged particles produced by the bare tungsten target(T4) are sensitive at the 15R flight path, while the permanent sweeping magnet exists
- Distance between the magnet to the collimator, collimation length, and the detection distance from the target, can be optimized to reduce charged particles contamination

Neutron flux measurement and MCNPX calculation



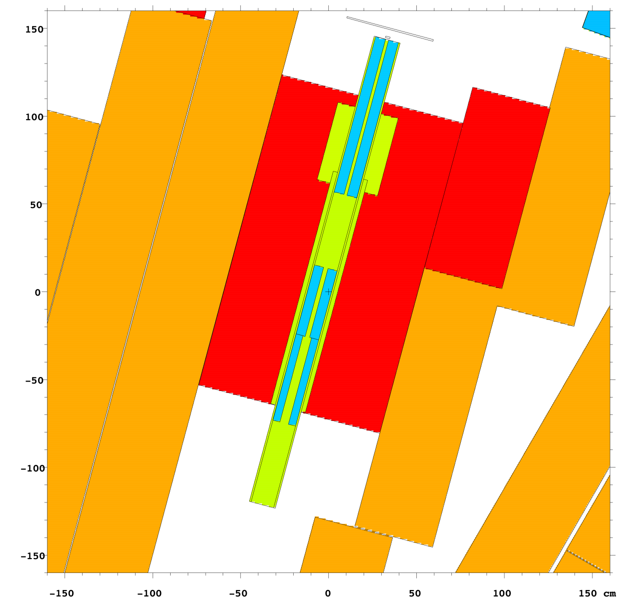
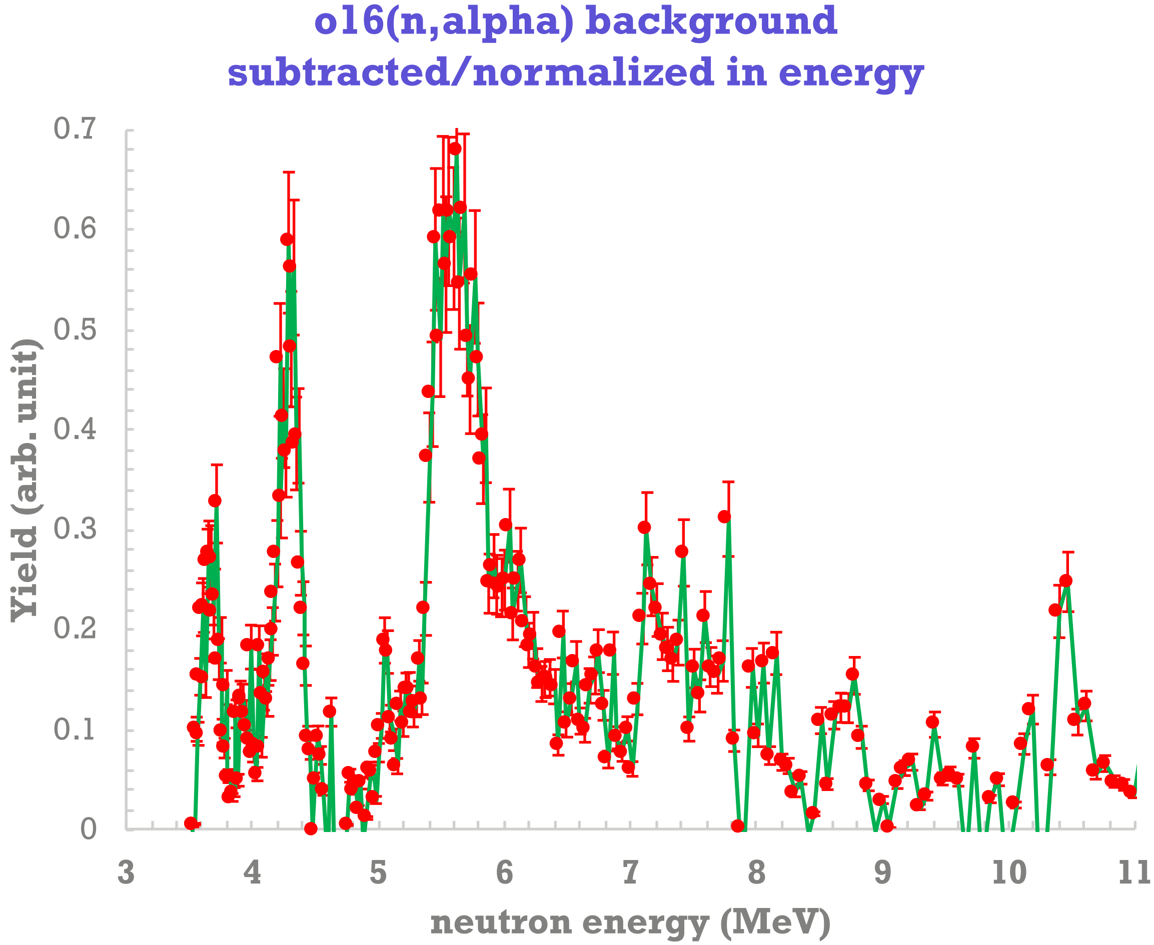


TABLE II: Itemized Uncertainty Budget

Ta_2O_5 Target thickness	3 %
Ta_2O_5 Target Amount	4 %
Ta_2O_5 Target Stoichiometry	< 0.5 %
WNR 15R Neutron Flux, including the ^{238}U foil non-uniformity & ionization counter efficiency	10 %
WNR 15R Neutron Energy Estimate	0.7 - 1.2 %
Silicon Strip Detector α's energy resolution	< 1 %
GEANT Validation	4 - 10 %
MCNPX Validation	4 - 10 %
Total systematic uncertainty	12.6 - 18.1 %
Total statistical uncertainty/ 65 keV	5-10 %
Total uncertainty	13.6 - 20.7 %

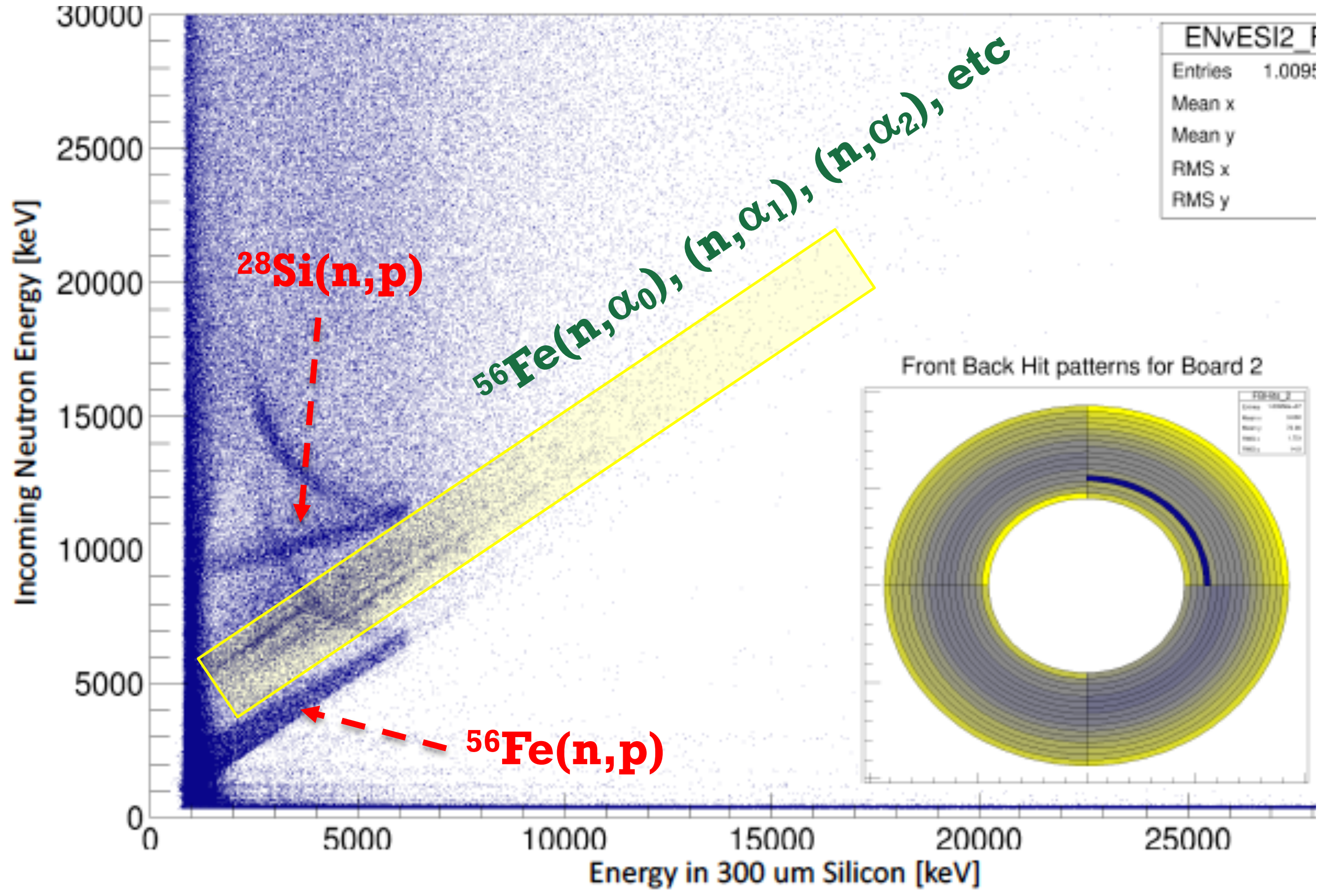
$^{16}O(n,\alpha)$ cross section preliminary result



1. Partial angular cross sections are summed here
2. Determining absolute cross section is under way

LENZ Campaign on Gas-Production Cross-Sections Measurements on Cr, Mn Fe, Co, Ni, etc.

^{56}Fe(n,α) measurement in 2017-2018 Run Cycle



- Interested in the neutron energy range up to 20 MeV as a broad coverage
- Used self-supporting, thin, and enriched targets with Ohio U. collaboration
- ΔE-E telescope in forward and backward angles are utilized
- LENZ is sensitive to differential cross sections to discrete levels and angles

Modification of angular distribution evaluation for (n,z) reactions: by H.I. Kim (KAERI)

Status of (n,p) and (n,α) reactions in ENDF/B-VIII.0

- Cr, Ni, Au
  - Cross sections (MF3) and DDX (MF6) for total (n,p) and (n,α)
- Ta
  - Cross Sections and DDX for total (n,p) and (n,α)
  - Discrete and continuum γ emission for total (n,p) and (n,α)
- Al, Zr, Cl
  - Cross section data for each level except ^{37}Cl(n,p)
  - Ang. Dist. for each level but almost flat
- Mn, Fe
  - Cross section for each level but no data for (n,α_{con})
  - Ang. Dist. for each level but almost flat
  - Discrete γ emission for discrete levels of (n,p) and (n,α)

Incomplete (n,z) reaction angular distributions in current evaluations
- No (n,z_0), (n,z_1), (n,z_2), etc. cross sections for all discrete levels
- Flat angular distributions assumed for most discrete levels

Modification of angular distribution evaluation for (n,z) reactions: by H.I. Kim (KAERI)

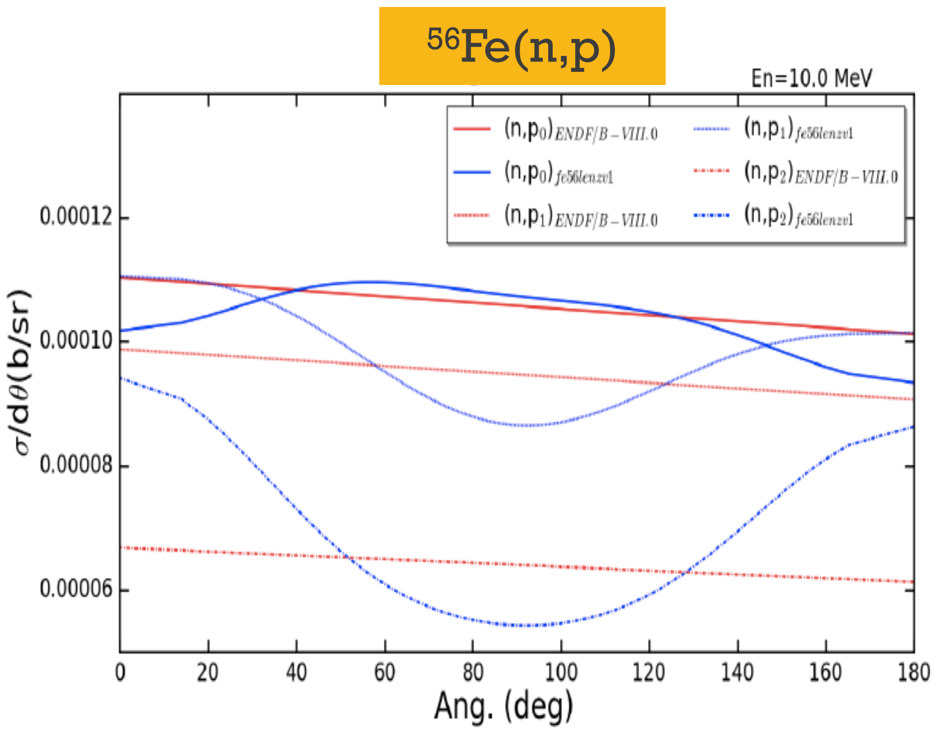
Summary for New Calculations

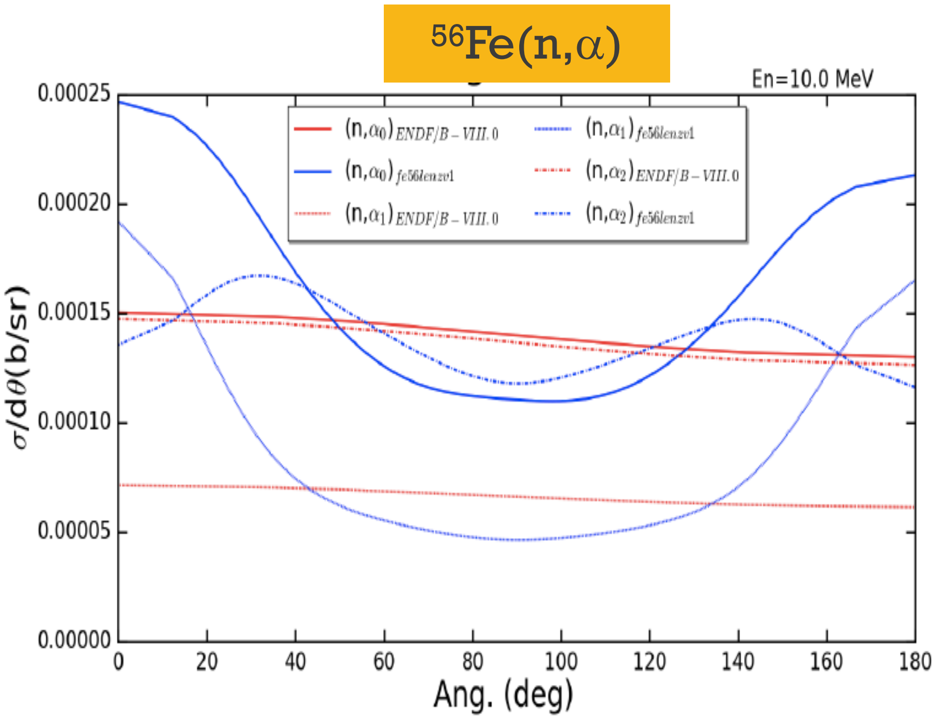
- Angular distribtutions
  - Calculated for all considered nuclides using CoH3
- Cross sections for discrete levels
  - Adopted
    - Al, Zr, Cl, Fe, Mn
  - Calculated and fitted
    - Cr, Ni, Au, Ta, ^{37}Cl(n,p)
  - Partially calculated and fitted
    - MT=869 (n,α_{cont}) for ^{54,56}Fe and ^{55}Mn
      $\Rightarrow$ Not applied to this version yet
      $\because$ necessary to modify related files such as MF3:MT5,MF6:MT5
- Number of discrete levels
  - Adopted nuclides: Same number
  - Calculated nuclides: 10 levels or up to maximum known levels

ACE formatted file list as of Nov. 7th 2018

Element	#	nucleus
Al	1	al27
Cl	2	cl35, cl37
Cr	4	cr50, cr52, cr53, cr54
Mn	1	mn55
Fe	4	fe54, fe56, fe57, fe58
Ni	5	ni58, ni60, ni61, ni62, ni64
Zr	5	zr90, zr91, zr92, zr94, zr96
Au	1	au197
Ta	1	ta181
Total	24	

New angular distributions for Fe-56 at E_n=10 MeV



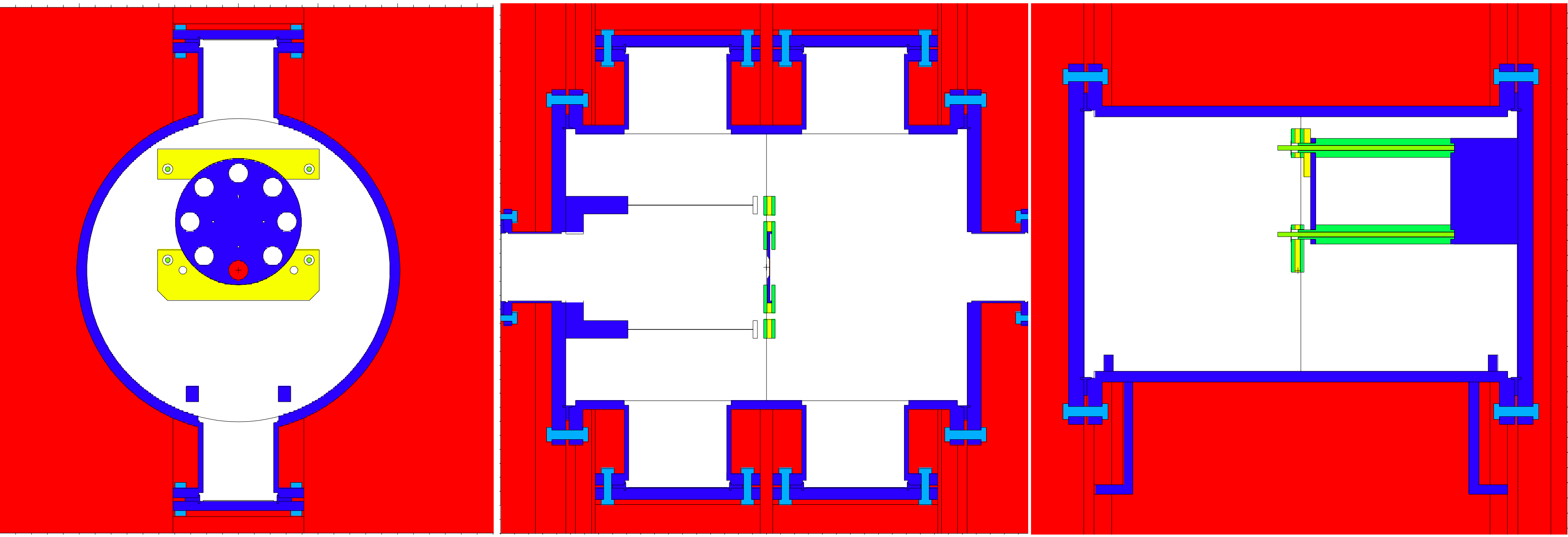


Cross sections are same with those of ENDF/B-VIII.0 by using same incident neutron energies and fitting to cross sections of ENDF/B-VIII.0

Red: ENDF/B-VIII.0 and **Blue: Present evaluation**

MCNP6 modeling for detector response study using ptrac

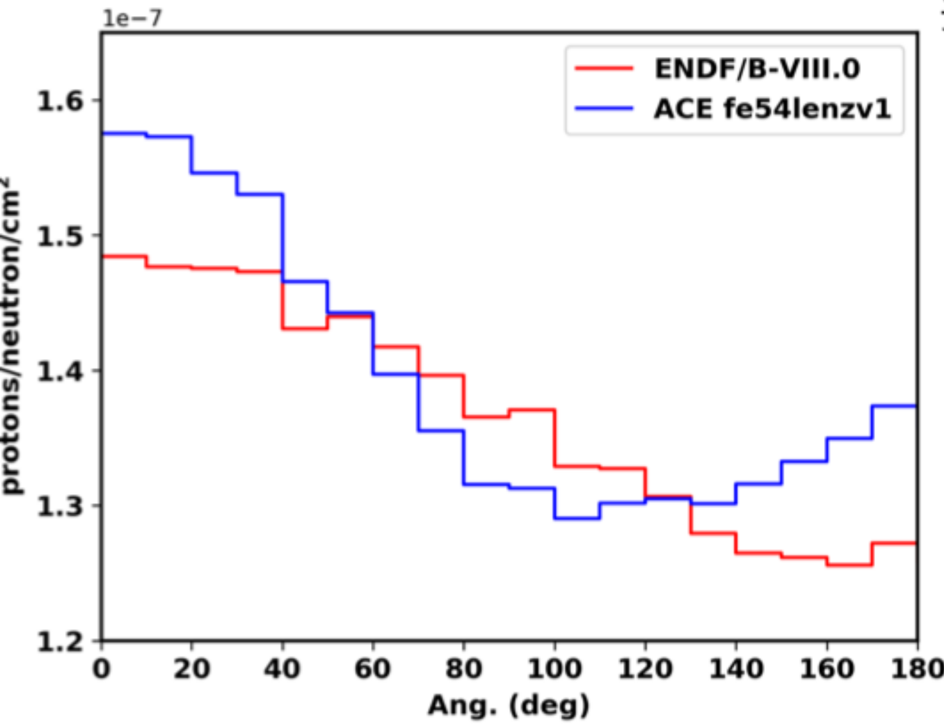
LENZ geometry is modeled using the MCNP6

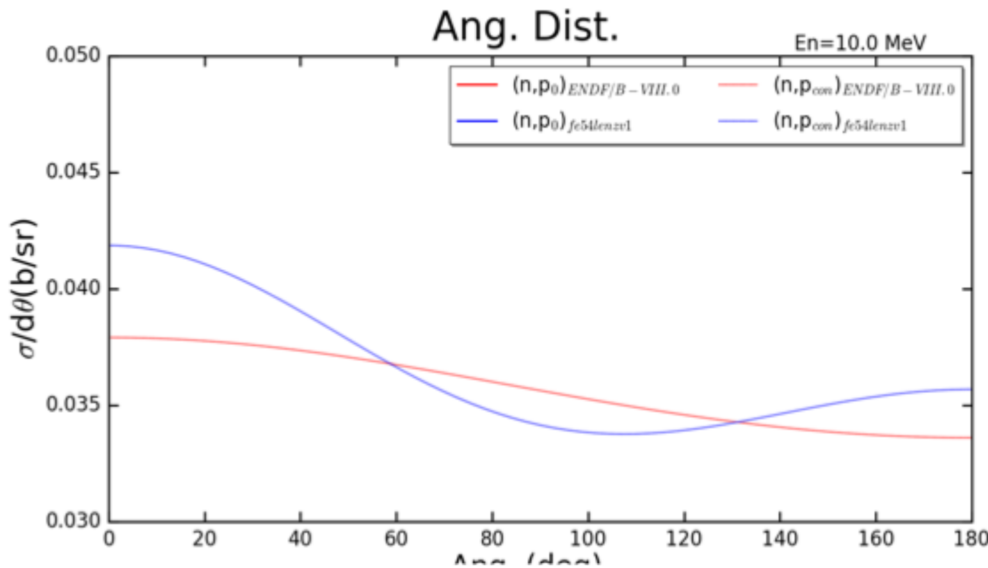


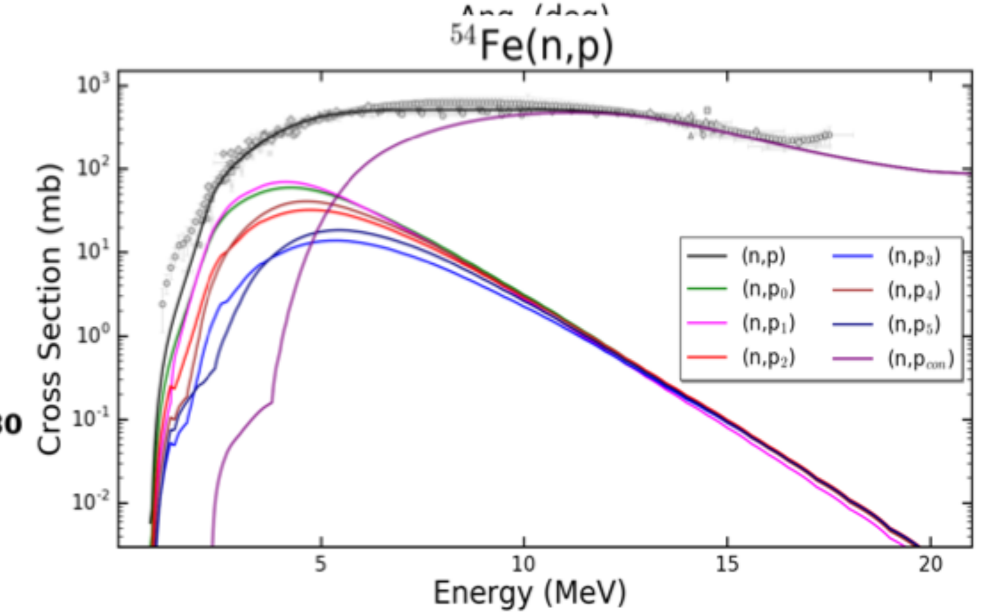
GEANT4 modeling is being validated using different nuclear input libraries, however we need to get the processed G4 library files from the CIEMAT effort (refer to INDC(NDS)-0758) for each new ENDF formatted evaluations.

^{54}Fe(n,p) reaction : MCNP validation

Tallied (n,p) angular distributions right after the target, in order to impact of the different evaluations

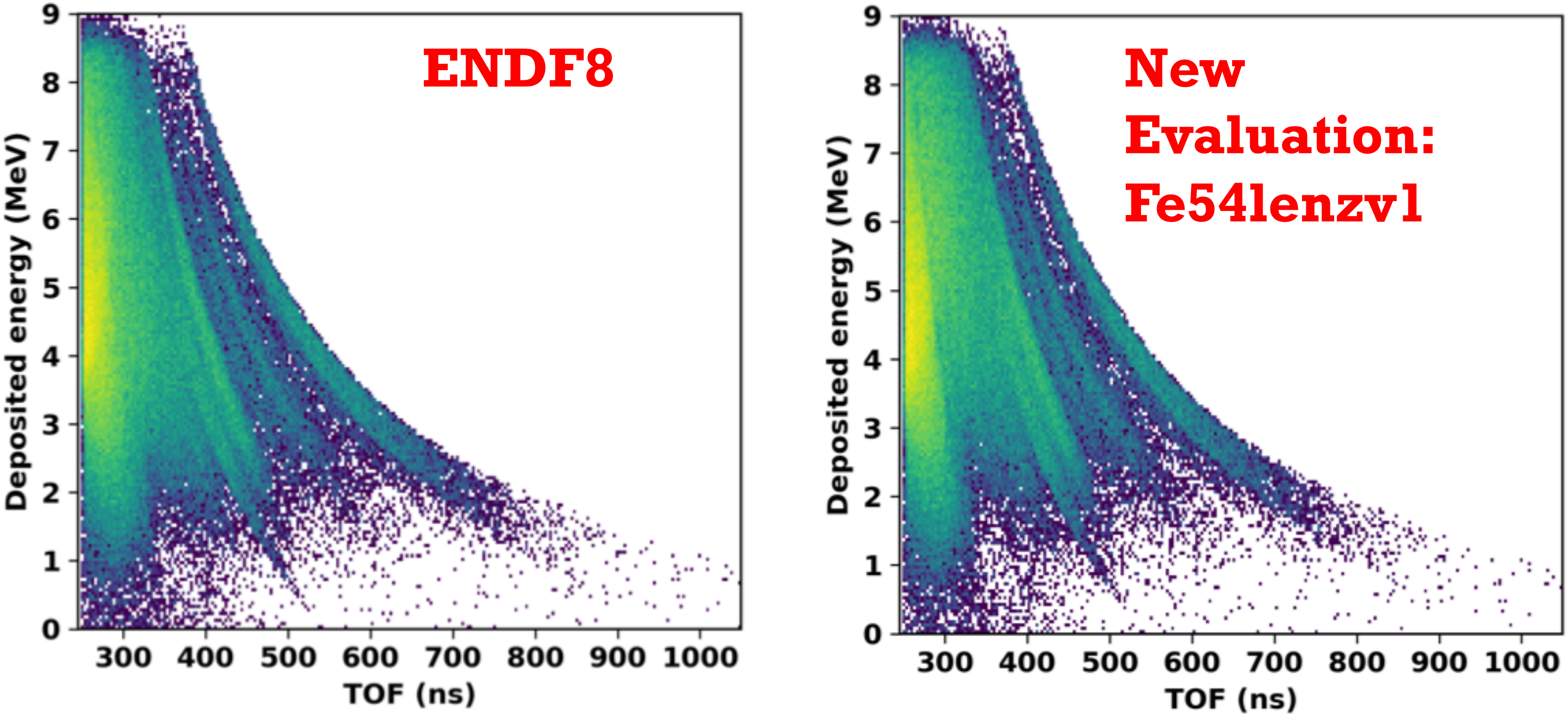




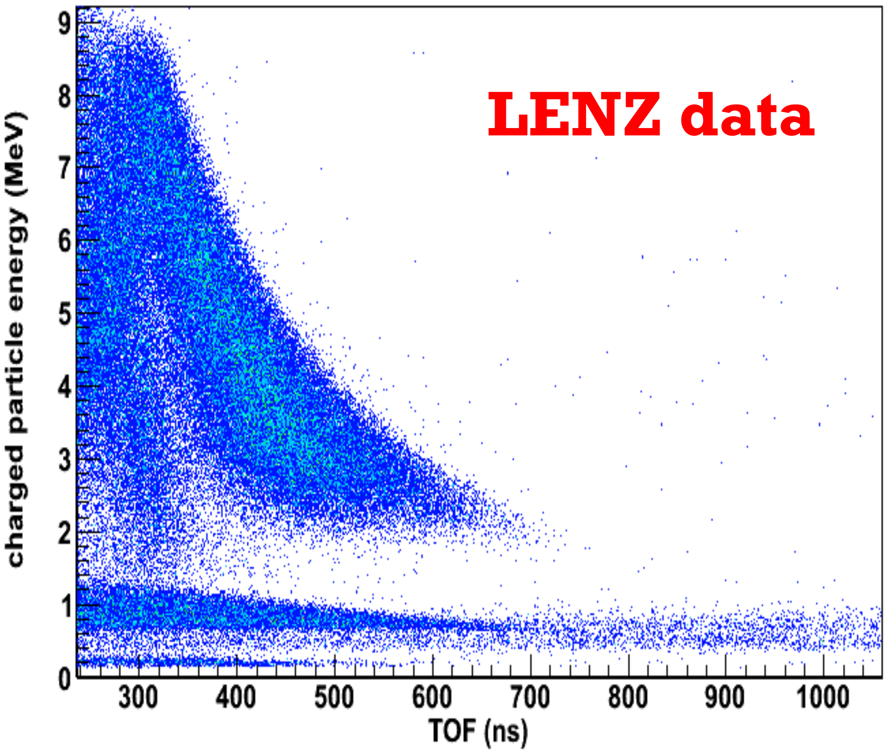


^{54}Fe(n,p) reaction: LENZ data simulation

LENZ data simulation for the DSSD 500 micron thick detector at 9.1 cm from the enriched, self-supporting ^{54}Ne target

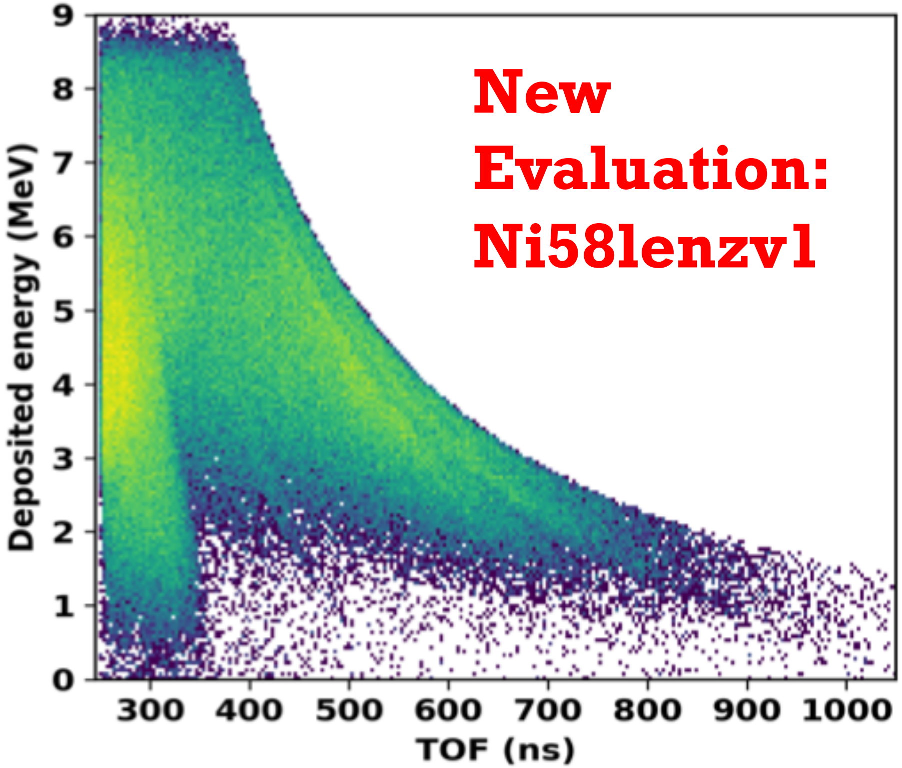


^{58}Ni(n,p) reaction : LENZ data and MCNP simulation -gross features compared



^{nat}Ni target with 10 μm thickness

All (n,z) reactions are shown

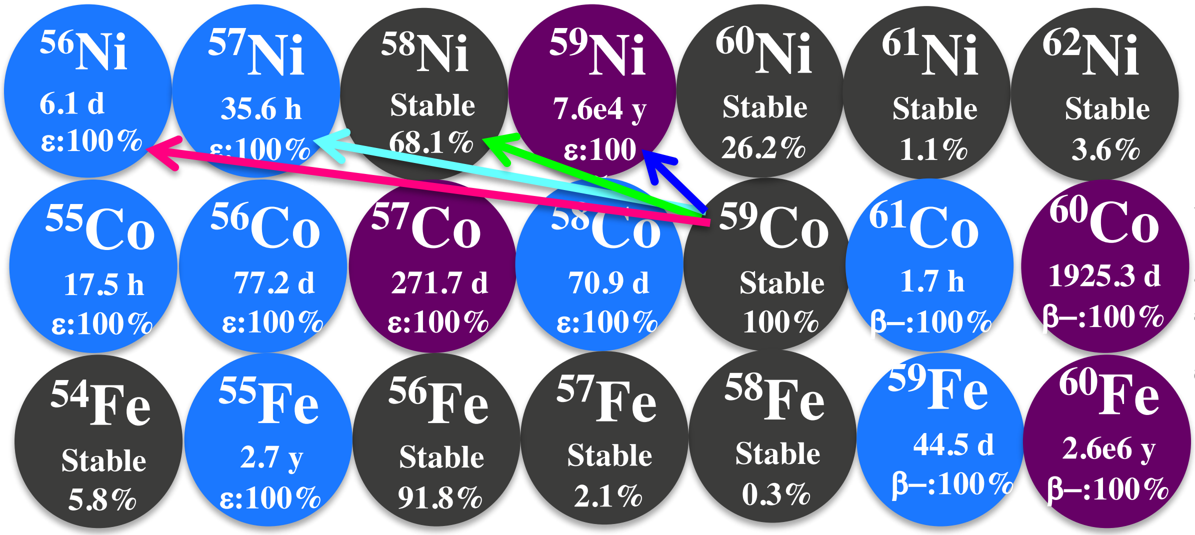


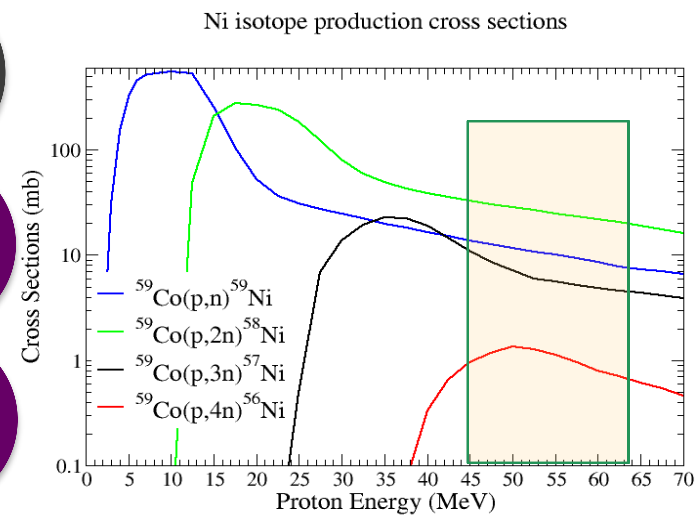
^{58}Ni target with 10 μm thickness

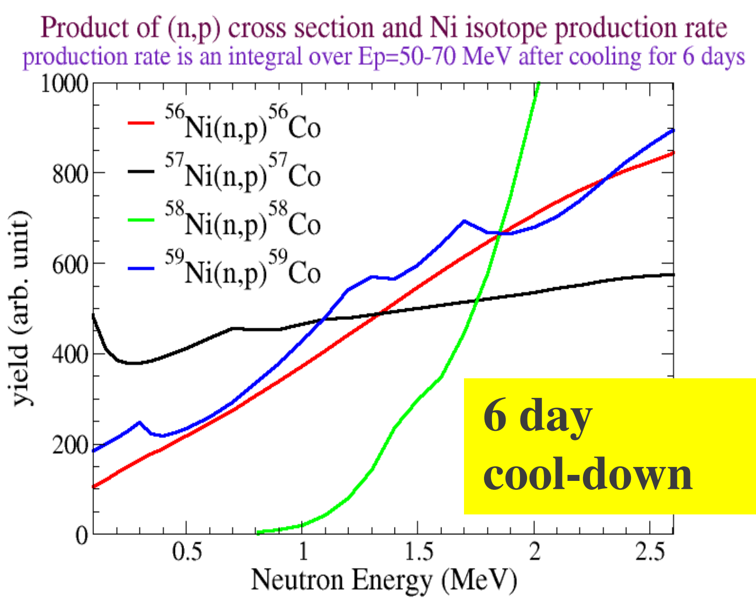
Tallied only (n,p) reaction

Plan forward: New LENZ data on ^{58}Ni, enriched foil (2 μm thick) for better resolved discrete-level cross sections with angular distribution

^{56}Ni Isotope Production at LANL-Isotope Production Facility

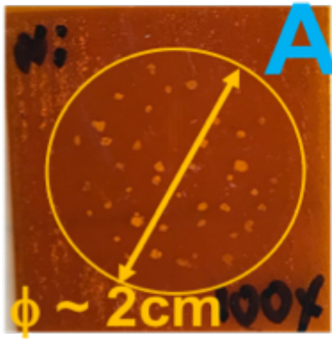


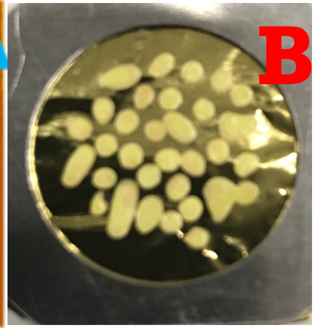




- For the interest of heavy ion production via neutrino-proton process in explosive supernovae, knowing the ^{56}Ni(n,p) reaction cross section is crucial ($T_{1/2}$~6 d)
- Until now, this direct measurement was impossible, due to the limited access to radioactive targets and unavailable neutrons
- First and the only effort in the world

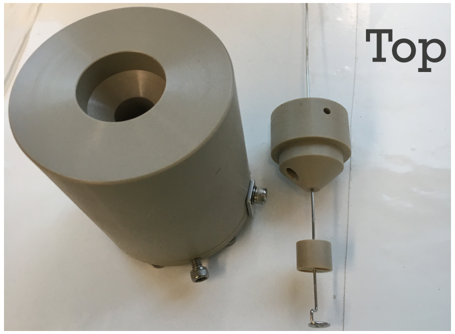
Radioactive Ni deposition to be a thin foil target

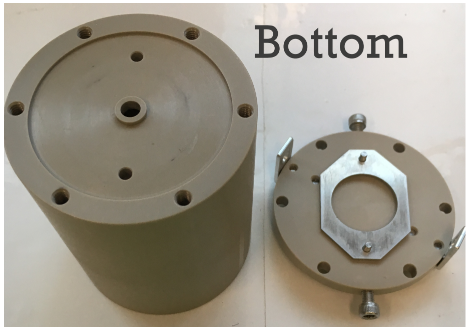


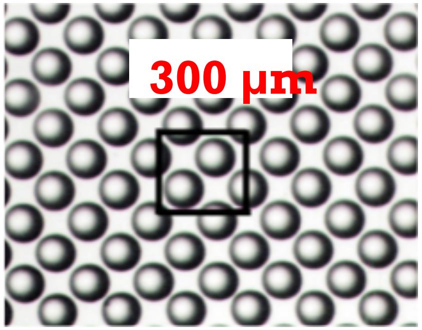


Small quantity (μg level) radioactive target requirements:
- High purity (For Ni targets, the $NiCl_2$-6(H_2O) is a solution after the chemical separation)
- Small backing material (optimize the reaction s/n ratio)
- Uniformity (To reduce charged particles' straggling)

Electrodeposition: Developed an optimized electodeposition device to be used in the Hot Cell with radioactive samples.
-can produce fairly uniform layer onto a 3 μm Au surface
-No other impurity other than Ni

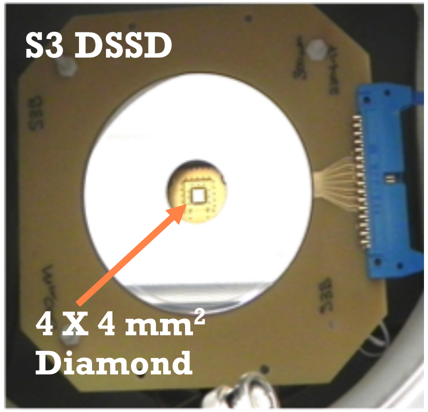






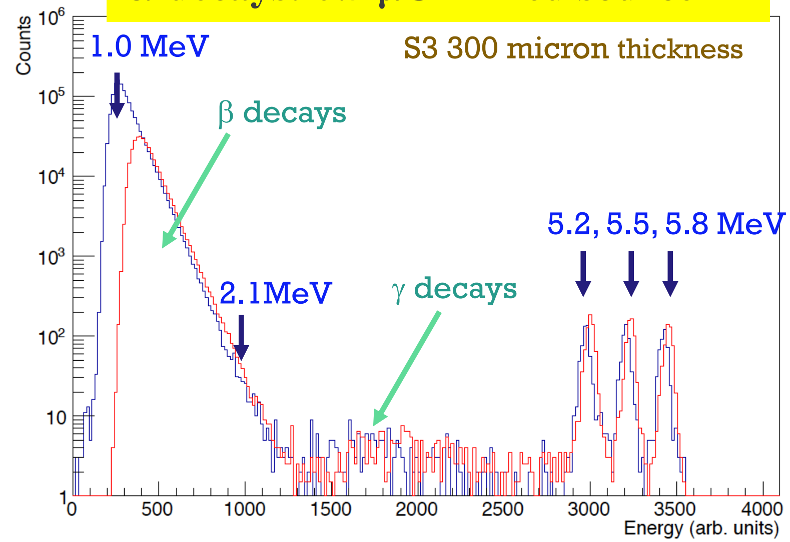
Micro-jet printing: Developing a NEW small-quantity radioactive target fabrication method, which manipulates tiny drops using a transducer for fluid at ambient pressure
-Able to print in precise location on material with 100 % efficiency
-Would print nickel salt, introducing impurities

Detector Performance Under High Radiation Environment



1. DSSD silicon detectors
2. small-area diamond-detector sandwich with a sample deposited on diamond detector

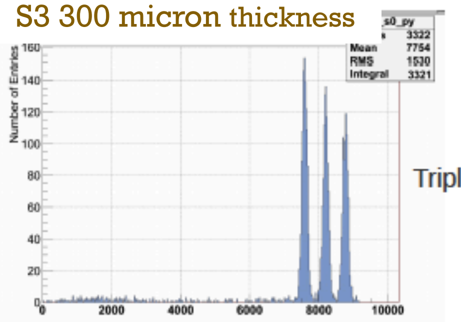
γ- & β- decays: 450 μCi ^{82}Sr
α-decays: 0.5 μCi mixed source



γ-decays: 100 μCi ^{152}Eu
α-decays: 0.5 μCi mixed source

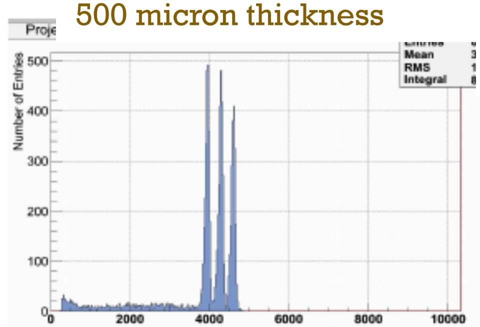
Silicon ... ond Detector

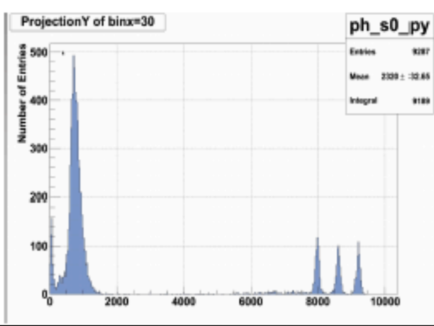
S3 300 micron thickness



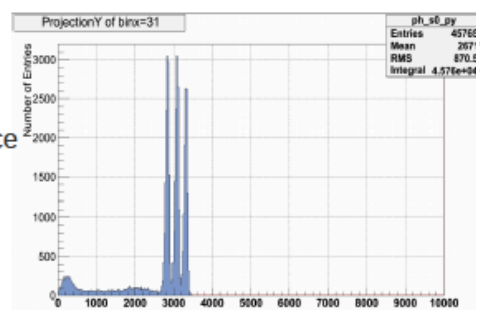
Triple α Source

500 micron thickness

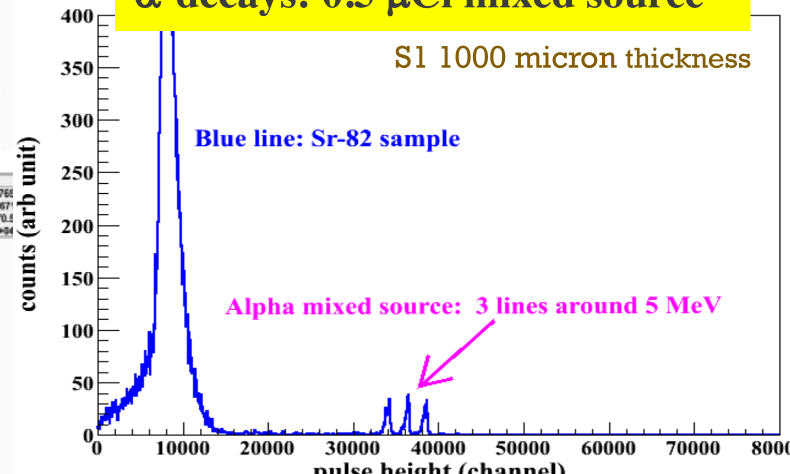




Triple α Source
With 100 μCi
Eu-152



γ- & β- decays: 55 μCi ^{82}Sr
α-decays: 0.5 μCi mixed source



Summary and Outlook

- LENZ measurements will provide high-quality differential data for better understanding of nuclear modeling for applications
- Continue on improving neutron-induced charged particle reaction data library (using EDNF V.III.0) in GEANT4 and MCNP6, such as differential cross section to discrete levels, angular distributions, etc., in conjunction with the "forward propagation analysis" on LENZ data
- In Dec. 2018, we plan to measure the long-lived ($T_{1/2}$~$7.6X10^4$ y) radioactive ^{59}Ni(n,p) reaction cross sections using the LENZ instrument as a benchmark for a direct measurement. In 2019, we plan to measure a final production of ^{56}Ni(n,p) reaction cross section.
- In the 2018 run cycle: we are collecting LENZ data on (red: radioactive nuclei)
  - ^{54}Fe, ^{56}Fe
  - ^{58}Ni, ^{59}Ni, ^{60}Ni
  - ^{35}Cl